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EFFECT OF FLOWS IN THE COLORADO RIVER ON
REPORTED AND OBSERVED BOATING
ACCIDENTS IN GRAND CANYON

(U.S.) Glen Canyon Environmental Studies
Flagstaff, AZ

Jan 87

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The Effect of Flows in the Colorado River on Reported and
Observed Boating Accidents in Grand Canyon

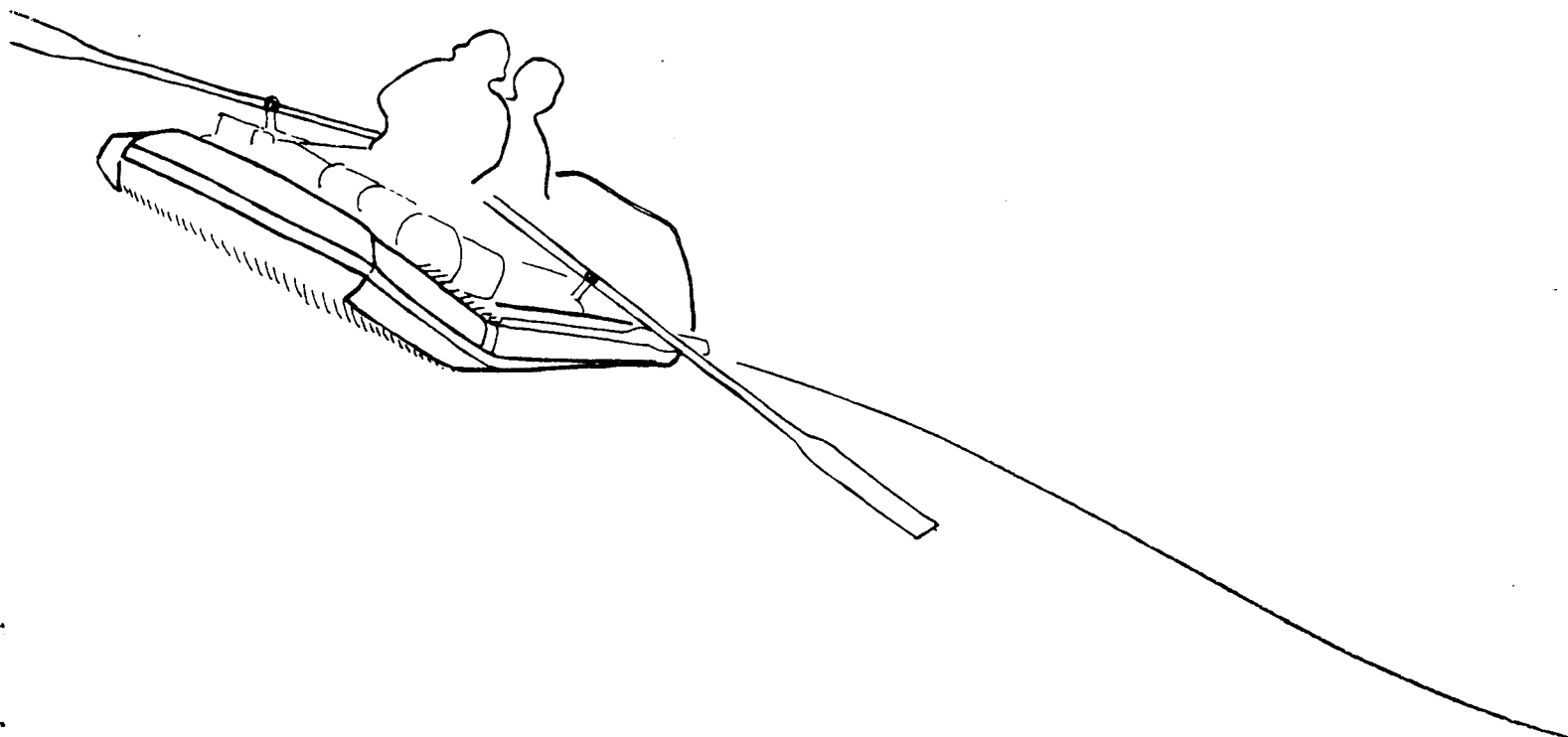
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While stationed on the river, observers were treated by the river community to extra food, ice, and friendship.

Abstract

This study examines the relationship between Colorado River flow levels and the incidence of white-water boating accidents in the Grand Canyon. The study covers the Colorado River between Lees Ferry (12 miles downstream from Glen Canyon Dam) and Diamond Creek, a distance of approximately 225 river miles almost entirely within Grand Canyon National Park.

To address the public concerns relating to the effect of Glen Canyon Dam operations on boating safety in the Grand Canyon, several accident studies were conducted, addressing the relative hazard associated with running rapids at different flow levels and during fluctuating flows:

- (1) Guide Survey: Mail survey of 385 commercial white-water guides to assess their judgments of the risk involved in running rapids at various flow levels.
- (2) Private White-water Boater Survey: Mail survey of 506 private white-water boaters, to assess their judgment of the risk of running Crystal Rapid at different flow levels.
- (3) Accident Records Study: Reviewed boating accident records from Grand Canyon for 1981 - 1983 covering 40 recorded serious boating accidents from 2,281 river trips. Assessed the relationship between recorded accidents and river flow levels.
- (4) White-water Observation Study: Observations of approximately 5,000 boats running rapids in Grand Canyon, 1985, 1986, recording problems and accidents occurring at different flow levels.
- (5) Flood Flow Survey: Phone interviews with parties running the Grand Canyon during the high flow (> 32,000 cfs) period, May 1 - June 15, 1986, covering 132 boats, focusing on difficulties running Crystal Rapid at high flows.
- (6) River Discussions: On-river discussions with approximately 303 white-water boating parties, Grand Canyon 1985, 1986, focusing on problems related to trip management under low flows and fluctuating flows.

These studies converged on the conclusion that river flow levels are related to white-water boating accident rates in a

statistically reliable fashion.

Guides and private boaters believe that river flow levels affect accident rates. Flood flows and Low flows are believed to be the most hazardous conditions, such that guides do not believe passengers can be carried safely below approximately 8,000 - 9,000 cfs or above 45,000 - 60,000 cfs, depending upon the type of boat employed. Fluctuating flows are not considered as significant a factor in river safety as flow level. The empirical analyses confirmed these perceptions.

The analysis of accident records show no significant overall relationship between flow levels and the reporting of serious accidents. However, for several reasons, this is a relatively weak test of the relationship between flow levels and accident rates. The accident records analysis did find a significant relationship between flows and accident rates at Crystal Rapid, with higher flows associated with substantially higher rates.

The observation study found significant associations, across ten major rapids, between river flows and the rate of four accident variables; losing control of an oar, hitting rocks, flipping and injuries. At Crystal Rapid, flow level was significantly related to six variables; hitting rocks, falling overboard, flipping, injury, walking around the rapid, and lining or portaging boats. All rates increased with flow level, except for hitting rocks, which decreased. Similar trends in accident rates and avoiding accidents are found at Lava Falls, although not as pronounced.

The current observation data on accidents at very low flows is quite limited, but show increased risk of hitting rocks, and trends towards increased accidents overall.

No differences were found in the accident variables between constant and fluctuating flows except for a very slightly higher rate of walking passengers around rapids during fluctuating flows.

The relationship between boat type and accident rate is stronger in most cases than the association between flow level and accidents. For example, at Lava Falls the rate of flipping varies by .12 across flow levels, but varies by .21 across boat types.

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Chapter I

INTRODUCTION

Purpose of the Study

This study examines the relationship between Colorado River flow levels and the incidence of white-water boating accidents in the Grand Canyon. It is part of the Glen Canyon Environmental Studies, a cooperative effort of the U. S. Bureau of Reclamation (USBR) and the National Park Service (NPS). The Glen Canyon Environmental Studies (GCES) are examining the impact of the operations of Glen Canyon Dam on the ecological and recreation resources related to the Colorado River in Glen Canyon National Recreation Area (Glen Canyon) and Grand Canyon National Park (Grand Canyon).

Study Area

Glen Canyon Dam is located on the Colorado River at Page, Arizona, near the Utah - Arizona state line. The dam, which forms Lake Powell, controls the flows in the river through Glen Canyon and Grand Canyon to Lake Mead. This study covers the Colorado River between Lees Ferry (12 miles downstream from the dam) and Diamond Creek, a distance of approximately 225 river miles almost entirely within Grand Canyon National Park.

In Grand Canyon, the river is used primarily by persons taking private and commercial white-water raft trips commencing at Lees Ferry and continuing through Grand Canyon National Park.

Background for the Study

Flows through Glen Canyon Dam are passed through the powerplant, the outlet tubes, or the spillways. Flows through the powerplant range from 1,000 cubic feet per second (cfs) to 31,500 cfs. Additional discharges through the outlet tubes or spillway may be added to powerplant releases. Generally, additional discharges are made only through the outlet tubes, producing maximum combined releases of 48,000 cfs. Very rarely, when inflows to the reservoir are extremely high, water may be passed through the spillways. This occurred in the Spring of 1983 when combined discharges reached 112,000 cfs.

In 1979, the Bureau of Reclamation proposed to study the po-

tential for installing two additional generators at Glen Canyon Dam. These generators would be used primarily to produce peaking power, and when in use could produce fluctuating outflows from the dam that might range from less than 3,000 to 33,000 cfs. Public response to the proposal indicated strong concern over the possible impacts of the peaking power plan on the ecology of the Colorado River and the use of the river by fisherman and boaters. Most germane to this study, public groups expressed concern that increased peaking power generation at Glen Canyon Dam, with its attendant fluctuating river flows, would degrade the present high quality boating experience in Grand Canyon National Park. Many of the concerns related to river safety. Boaters were concerned that very high discharges, very low discharges, and rapid rates of fluctuation would all increase the hazards of running the many difficult rapids in the Grand Canyon, leading to an increase in the incidence of rafting accidents and injuries.

Based on these public concerns, the USBR and the NPS agreed to initiate the Glen Canyon Environmental Studies, to jointly study the environmental and recreation impacts of current Glen Canyon Dam operations. This would be done before changes in operations were considered.

Before describing the studies conducted to address impacts on white-water boating safety, we first describe the types of boating accidents that occur in the white-water section of the river.

Accident Setting

The Colorado River in the Grand Canyon presents an unusually severe hazard for white-water boaters. It is not uncommon in the many difficult rapids for persons to fall out of their boat, either when hit by waves crashing over the boat or when the boat is flipped in a rapid. While the vast majority of persons falling into the river are recovered with consequences no worse than a cold bath, any person overboard is a potentially serious situation. In addition to the powerful currents and turbulence, the very temperature of the water is life threatening. Water released from deep within Lake Powell at Glen Canyon Dam has a temperature of 42 degrees F, and over its 200 mile journey through the Canyon warms only to 50 degrees F. Persons falling into the water have only a few minutes of useful activity before hypothermia prevents coordinated physical effort.

Since 1980, five persons have died while running the white-water in the Grand Canyon; two at Lava Falls, three at Crystal Rapid. Two of the persons were running in large,

30-foot motor rigs, two in 16-foot oar rafts, one in a 16-foot paddle raft. All deaths resulted from falling into the water, in four of the cases after the boat had flipped in a rapid. Cause of death in four cases was drowning, in one case heart failure. It is important to note that these deaths occurred after relatively brief periods of immersion, with the victims wearing life vests in four of the five cases.

This record speaks to the serious hazard posed by the very cold and turbulent waters that rapidly exhaust, and can render unconscious, even the strongest swimmer. For this reason, falling out of a boat in Grand Canyon white-water, while usually only a chilling experience, carries the potential for serious harm.

Other more common and usually less serious types of injuries include getting hands or feet crushed between boat frames and tubes as the boat flexes in rapids, being struck by or hurled against boat equipment or other passengers, and injuries to joints while paddling in heavy currents.

While white-water boating can be hazardous, it is the challenge and risk associated with large rapids that attract river runners and define the essence of the white-water experience. Without the hazards and uncertainties associated with the white-water, much of its special appeal would be lost. This issue is addressed further in the Discussion chapter at the end of this report.

Chapter II

STUDIES

Approach

To address the public concerns relating to the effect of dam operations on boating safety in the Grand Canyon, several accident studies were conducted, collecting and analyzing several kinds of data addressing the relative hazard associated with running rapids at different flow levels and during fluctuating flows. These are summarized below.

- (1) Guide Survey: Mail survey of 385 commercial white-water guides to assess their judgments of the risk involved in running rapids at various flow levels (part of a larger survey, GCES Report C-2).
- (2) Private White-water Boater Survey: Mail survey of 506 private white-water boaters, to assess their judgment of the risk of running Crystal Rapid at different flow levels (part of a larger survey, GCES Report C-2).
- (3) Accident Records Study: Reviewed boating accident records from Grand Canyon for 1981 - 1983 covering 40 recorded serious boating accidents from 2,281 river trips. Assessed the relationship between recorded accidents and river flow levels (GCES Report C-2).
- (4) White-water Observation Study: Observations of approximately 5,000 boats running rapids in Grand Canyon, 1985, 1986, recording problems and accidents occurring at different flow levels.
- (5) Flood Flow Survey: Phone interviews with parties running the Grand Canyon during the high flow ($> 32,000$ cfs) period, May 1 - June 15, 1986, covering 132 boats, focusing on difficulties running Crystal Rapid at high flows.
- (6) River Discussions: On-river discussions with approximately 303 white-water boating parties, Grand Canyon 1985, 1986, focusing on problems related to trip management under low flows and fluctuating flows.

The basic approach in all of these studies was to correlate boating accidents and other problems with river flow level. Flow levels corresponding to each accident were obtained from Glen Canyon dam release records, gauging stations in

Glen and Grand Canyon, and by extrapolating dam releases to downstream points using the Streamflow Synthesis and Reservoir Regulation Model (SSARR) (GCES Report D-1).

All accident studies divided the range of Colorado River flows into four categories; Low: < 9,000 cfs; Medium: 9,000 - 15,999 cfs; High: 16,000 - 31,500 cfs; and Flood: > 31,500 cfs.

Surveys of White-water Guides and Private Boaters

Experienced white-water guides have run the Grand Canyon under a wide range of river flows, both steady and fluctuating. They have experienced the relative difficulty of running the many rapids at these flows and can judge where and at what river flows accidents are more likely to occur.

The data reported here are taken from a 1985 survey of 385 Grand Canyon white-water guides conducted as part of the GCES Recreation Studies (GCES Report C-2). The guides (commercial motor guides, commercial raft guides, and private trip leaders), average approximately 9 years experience, and have run the river under a range of conditions. The commercial guides, on average, have experienced river levels that range from 4,000 to 80,000 cfs while the private trip leaders have a reduced range of experience, 12,000 to 42,000 cfs.

One issue addressed in the survey was the perception of experienced guides concerning the relationship between river flow levels and boating accidents.

The guides were asked to rank, from 1 (most important) to 7, possible causes of boating accidents on the Colorado River. Table 1 shows the average rank for each factor. While flow-related factors are ranked only third, fourth and next to last, it is clear that very high and very low flows are perceived as more relevant to accidents than the presence of daily flow fluctuations.

Table 1

White-water Guide's Ranking of Causative
Factors in Boating Accidents

	Average Rank
Boatman inexperience	2.3
Boatman error	2.8
Very low water (<5,000 cfs)	3.1
Very high water (>45,000 cfs)	3.7
Equipment failure	4.6
Daily fluctuations	4.9
Weather	6.5

The guides were next asked whether they thought accidents were more likely to happen at certain flows and, if so, to identify which flow ranges were more likely to result in accidents. Eighty-seven percent felt accidents were related to flows. These guides were then asked which flow levels are more likely to produce accidents. The guides singled out very high and very low flows as increasing accident rates.

Flow level	Percent believing flow level increases risk of accidents
< 5,000 cfs	90%
5,000 - 8,999	55%
9,000 - 15,999	10%
16,000 - 31,999	5%
32,000 - 45,000	29%
> 45,000 cfs	80%

A similar question was asked concerning the relationship between flow levels and severe accidents:

"Do you feel that more severe accidents (such as flipping a boat or serious injuries to trip members) are more likely to happen under certain flow levels than at others?"

- 11% No, I think that the severity of accidents is not related to flow level.
- 89% Yes, I think more severe accidents are likely to happen at the following flow levels.
 - 80% Flows less than 5,000 cfs
If so, where? Horn Creek, Hance
 - 48% 5,000 - 8,999 cfs
If so, where? Horn Creek, Hance
 - 18% 9,000 - 15,999 cfs
If so, where? Lava Falls, Horn Creek
 - 14% 16,000 - 31,999 cfs
If so, where? Crystal, Lava Falls
 - 42% 32,000 - 45,000 cfs
If so, where? Crystal, Lava Falls
 - 87% Above 45,000 cfs
If so, where? Crystal, Lava Falls

This question, focusing on severe accidents, gives very similar results, but also identifies specific problems with Horn Creek and Hance Rapid at low flows, and Crystal Rapid and Lava Falls at high flows.

Guides were also asked to identify the minimum and maximum constant flow levels for running rapids safely with passengers. The three groups of guides specified minimum safe flow levels ranging from 8,400 to 9,200 cfs, and maximum safe flow levels ranging from 47,000 to 59,000 cfs.

Persons taking private white-water trips also may have run the river under a range of conditions. As part of a 1986 survey conducted for the GCES Recreation Studies (GCES Report C-2), private white-water boaters were asked about the risk of running rapids at various flow levels. They reported their estimate of the chances of flipping in Hance or Crystal rapid in the type of boat they normally use, at each flow level, and whether such a risk of flipping would be accept-

able to them. Table 2 shows their responses.

Table 2

Private White-water Boater's Judged Proportion of Boats
that Would Flip at Various Flow Levels¹

	Flow Category			
	3-9	10-15	16-31	>31
Hance Rapid ₂ (unacceptable) ²	.05 (9%)	.05 (5%)	.10 (5%)	.15 (11%)
Crystal Rapid ₂ (unacceptable) ²	.07 (13%)	.10 (7%)	.20 (6%)	.25 (27%)

¹ median prediction

² percent judging accident rate unacceptable

Private boaters indicate that risk increases for both rapids with increasing flows, and there is a parallel reduction in the willingness to run the rapid. (It is notable that, in the Spring of 1986 when flows were ranging from 40,000 to 50,000 cfs, a significant proportion of the private parties scheduled to run the river cancelled their trips, citing the high water levels as their reason. This was a major decision for these parties, because it meant moving to the bottom of the five-year waiting list for their next opportunity to run the river.)

Private trip leader's beliefs about flow levels and accidents closely follows the judgments of the white-water guides for Crystal Rapid, and for Hance Rapid at high flows. The divergence between private boaters and guides concerning the hazard at low water for Hance Rapid may be due to the fact that the guides were asked to consider all accidents (including hitting rocks), while private boaters estimated only the rate of flips, which may not be as much of a problem at low water. Also, the private group, sampled from the high-water year of 1985, may have had less experience with Hance at low water than the guides.

Conclusions

Both white-water guides and private boaters believe that accidents are related to higher flow levels, and guides believe that very low water may also be associated with higher accident rates. Guides suggest that water levels are less important a cause of accidents than boatman inexperience and error. Fluctuating flows are judged to be less of a cause of accidents than extreme water levels. Guides single out Horn Creek and Hance rapid as particular problem areas at low water, and Crystal Rapid and Lava Falls as difficult rapids at high water.

Accident Records Study

One approach to confirming the judgments of experienced white-water boaters is to examine past records of boating accidents and determine whether a correlation exists between these accidents and river flow levels. This analysis of boating accident records in Grand Canyon was conducted by A. H. Underhill, M. H. Hoffman, and R. E. Borkan, of the Cooperative National Park Service Studies Unit, University of Arizona (GCES Report C-1).

Method

The incidence of reported boating accidents was correlated with river flow levels for the years 1981, 1982 and 1983. This was done by examining whether a disproportionate number of reported accidents occurred at any river flow level when compared to the number of boat trips at that flow.

Accident Reports. The frequency of accidents was measured using the accident reports compiled by NPS personnel on the standard NPS Case Incident Record. These reports are filed whenever (1) a medical evaluation is performed by NPS staff, (2) evacuation of an injured person occurs, or (3) an accident resulting in over \$200 damage is reported. Therefore, the accidents covered by these reports are major, involving significant damage, severe injury or fatalities. These records covered 40 accidents during the three-year study period.

Boating Population. The total population of boats in the study period was 7,727. To measure the population of boats at each flow level, river checkout sheets completed at the

Lees Ferry launch site were examined. This provided information on the time of launch, type of boats and number in party. The SSARR model was used to estimate the river flow at the time and location of each accident.

Analysis

To calculate accident rates for the four flow categories it is necessary to know both how many boats had accidents at each flow level and how many boats did not. The SSARR model was used to assign each accident to a flow category. However, it was not possible to track the movements of boats which did not have accidents. Therefore, to estimate the proportion of boats running at each flow level, the number of "boat-hours" in each flow category was calculated. For example, if dam releases for one day were 8,000 cfs for 12 hours and 14,000 cfs for the remaining 12 hours, and 100 boats were on the river that day, the result would be 1200 boat hours at Low flows, and 1200 boat hours at Medium flows. Although this method is not precise, it consistently produces the proper proportion of boat-hours in each flow range.

If river flow level has no effect on accident rate, we would expect the proportion of the total accidents that fall in each flow category to equal the proportion of total boating-hours in each flow category. That is, the only thing that would affect the number of accidents observed at each flow level would be the number of boats at each level.

The chi-square test for association was used to test for a relationship between flow and accident rate, because of the extremely low (0.5% or less) accident rates. Chi-square is typically used to test for association among variables with low incidence rates (Glass, 1984).

Results

The first line in table 3 shows the percent of the total boat-hours in each flow category. As shown, approximately 29% of the boat-hours occurred during Low flows, 25% during Medium flows, 35% during High flows, and 11% during Flood flows. This provides the theoretical or expected proportion of accidents for each category. By multiplying the percentage in each category by the total number of boating accidents, we arrive at the number of accidents expected in each category if there is no relationship between flows and accident rate. These expected values are shown in the next line. The third line shows the actual number of accidents recorded in each flow category during the study period, and

the last line shows the percent of reported accidents occurring in each flow category.

Table 3

Boating Hours, Expected and Reported
Accidents in Each Flow Category: 1981 - 1983.

	Low	Medium	High	Flood
Percent of total boating hours	29%	25%	35%	11%
Expected accidents	11.56	10.00	14.20	4.24
Reported accidents	9	14	10	7
Percent of accidents in each category	22%	35%	25%	17%

$$\chi^2 = 5.21 \quad p > .05$$

The chi-square statistic reported at the bottom of table 3 indicates the degree to which the reported number of accidents in each flow category departs from the number that would be expected if flows were unrelated to accident rate. In this analysis the chi-square statistic indicates that the number of reported accidents for each flow category do not depart significantly from the expected number.

The same analysis was done for each of the study years separately. The results for the individual years also showed no significant relationship between flow levels and accident rates. The chi-squares were: 1981 $\chi^2 = 5.135$, $p > 0.05$; 1982 $\chi^2 = 0.828$, $p > 0.05$; 1983 $\chi^2 = 3.047$, $p > 0.05$.

Underhill, et. al. also found no relation between type of boat used and recorded accidents overall, but found that motor rafts had a significantly higher rate of accidents at Crystal Rapid at Flood flows. The data also suggested that accidents increase for all boats at Horn Creek below 11,000 cfs, although the number of incidences was too small to test statistically.

Conclusions

The analysis of accident records suggested that no significant relationship exists between flow levels and reported accidents when assessed across all rapids. The only significant relationship between reported accidents and flows occurred at Crystal Rapid, with motor rigs having more accidents at Flood flows.

However, the ability of this analysis to detect such relationships is limited by several factors. First, the accidents reported are only the most severe injuries requiring evacuation. This means that only a fraction of the kinds of boating mishaps are recorded. Many kinds of accidents may not be represented in this data base; for example, loss of equipment, unreported equipment damage, boat flips, persons overboard, minor injuries, striking rocks, etc.

Second, the incidence of serious accidents requiring evacuation is very low (0.52%). This makes the power of the statistical test to detect a relationship between flows and accidents quite low.

Finally, the reliability and completeness of the accident reports is unknown. We cannot be certain that all serious accidents were reported or properly recorded. This adds error to the analysis and further reduces the power of the statistical tests.

Based on a need for a more complete assessment of the relationships between river flows and the full range of accidents, the accident observation study was implemented.

Accident Observation Study

The purpose of the observation study was to assess the relationship between flows and accident rate with a study design that (1) addressed the full range of boating incidents and accidents, thereby providing a more sensitive measure of boating hazard, (2) was based on direct observations of accidents, and (3) evaluated enough data points to provide a strong test for the existence of any relationship between accidents and river flows.

Method

Observers were placed in the Grand Canyon at selected rapids. For each boat running the rapid, characteristics of the run were recorded. The observation variables were selected to cover the range of "accidents" that could occur, from losing grip of an oar in a rapid to serious injury and fatalities. The variables measured were:

1. Time and date of run.
2. Type of boat: motor rig, large raft, small raft, kayak, canoes & inflatables, dories.
3. Type of trip; private or commercial.
4. Starting point for route taken through rapid (left, right or middle).
5. Whether the party scouted the rapid.

Whether any of the following happened to the party:

6. Lost control of an oar: refers primarily to boaters in rafts and dories losing grip of an oar.
7. Flipped: for kayaks, coded only if the boater came out of the boat. For all others refers to overturning.
8. Struck a rock.
9. Persons overboard.
10. Length of time persons were in the water: the maximum amount of time any person from a boat spent in the water.
11. Most serious injury: broken into categories of Slight, Incapacitating (requiring evacuation), Life-Threatening, and Fatality.
12. Equipment lost or damaged: covers both equipment lost from a boat and damages.
13. Number of persons who walked around rapid.

14. Boat was portaged or lined through rapid:
included all boats carried around or through a rapid, or lined through empty.

These variables were recorded using a structured checklist for which observers needed to check only positive instances, i.e. a check was made for "flip" only if a flip occurred.

The observers also held discussions with members of each party, if the party put to shore. These discussions focused on problems the party had in other reaches of the river, particularly problems related to fluctuating river flow levels, e.g., waiting for the water to rise before running a rapid, dragging boats that were hung-up on beaches when the river level dropped.

Observers. Observers were recruited from the Student Conservation Association (SCA), Volunteers in the Park program (VIP), Bureau of Reclamation and National Park Service. The SCA and VIP programs provide natural resource agencies with volunteers seeking experience in resources management. Based on applications and interviews, six SCAs and 32 VIPs were selected from to assist in the study. Also, one NPS and five USBR employees assisted to fill areas not covered by volunteers.

Observers were trained in the use of standardized checklists and discussion forms, including practice rating videotapes of boats running rapids, as well as field practice.

Observers were placed in the Grand Canyon in groups of two so that observer duties could be split. They were accompanied to their locations by the study manager or training specialist. Binoculars were provided.

Sample Size. A statistical power analysis was conducted to determine the sample sizes necessary to provide an appropriate test for any relationship between accidents and river flows. This analysis requires selecting a variable that the study will target, and a change or difference on that variable that the study will be designed to detect. The target variable selected was the proportion of boats flipping in a rapid. The study team estimated that approximately 5 percent of boats running Lava Falls would flip at moderate flows. The target sample sizes were selected to provide an 80% chance to detect an increase from .05 to .15 rate of flips between flow categories, at the .05% confidence level. This requires approximately 130 observations at each of the 4

flow levels (Cohen, J., 1977).

Study Period and Rapids Observed. The study was conducted in four phases. The observation rapids were selected to cover rapids with historically high rates of incidents and accidents. The pretest phase covered August 23 to September 24, 1985, with observers at Crystal Rapid and Lava Falls. For the second phase, from September 25 to December 10, 1985, additional observers were added at Hance Rapid. The third phase, June 11 - 20, 1986 was added to cover high spring flows, with observers just at Crystal Rapid. In the last phase, from July 26 - August 16, 1986, additional rapids were added which had been frequently mentioned as trouble spots during discussion with boaters. This phase covered Houserock Rapid, 24 1/2 Mile Rapid, 25 Mile Rapid, Hance Rapid, Horn Creek Rapid, Granite Rapid, Crystal Rapid, Deubendorf Rapid, Upset Rapid, and Lava Falls.

The study covered periods of both steady flows (no changes greater than 10,000 cfs in a 24 hour period), and fluctuating flows (daily changes in flow level greater than 10,000 cfs.)

The types of flows covered in each observation period were:

August 23 - September 24, 1985:

Steady flows ranging from 24,000 to 29,000 cfs

September 25 - December 10, 1985:

Steady flows ranging from 24,000 to 29,000 cfs, and
Flows fluctuating daily from 5,000 to 27,000 cfs

June 11 - June 20, 1986

Steady flows ranging from 30,000 to 32,000 cfs

July 26 - August 16, 1986:

Steady flows ranging from 24,000 to 29,000 cfs, and
Flows fluctuating daily from 5,000 to 27,000

Flow level calculations. Each boat observed running a rapid constituted a data case. Associated with each boat were the observation variables plus a river flow level derived using the SSARR model. This model takes flows at the dam and routes them downstream to 5 locations; Lees Ferry, Little Colorado River, the Grand Canyon gauge at Phantom Ranch, National Rapid, and Diamond Creek.

The flows at each observation rapid were estimated by interpolating between the two nearest SSARR locations. However, prior to the interpolation, the upstream and downstream SSARR

location flows were adjusted to reflect the travel time of those flows to and from the observation point.

For example, Hance Rapid is approximately 2 hours downstream of the Little Colorado River SSARR location, and 2 hours upstream of the Grand Canyon SSARR location. Thus, to estimate the flow at Hance Rapid for 8 AM, one interpolates between the flow at the Little Colorado River at 6 AM (-2 hours), and the flow at Grand Canyon at 10 AM (+2 hours). In this case the estimate for Hance is simply the average of the adjusted flows, since Hance is equidistant from the two SSARR points.

Data

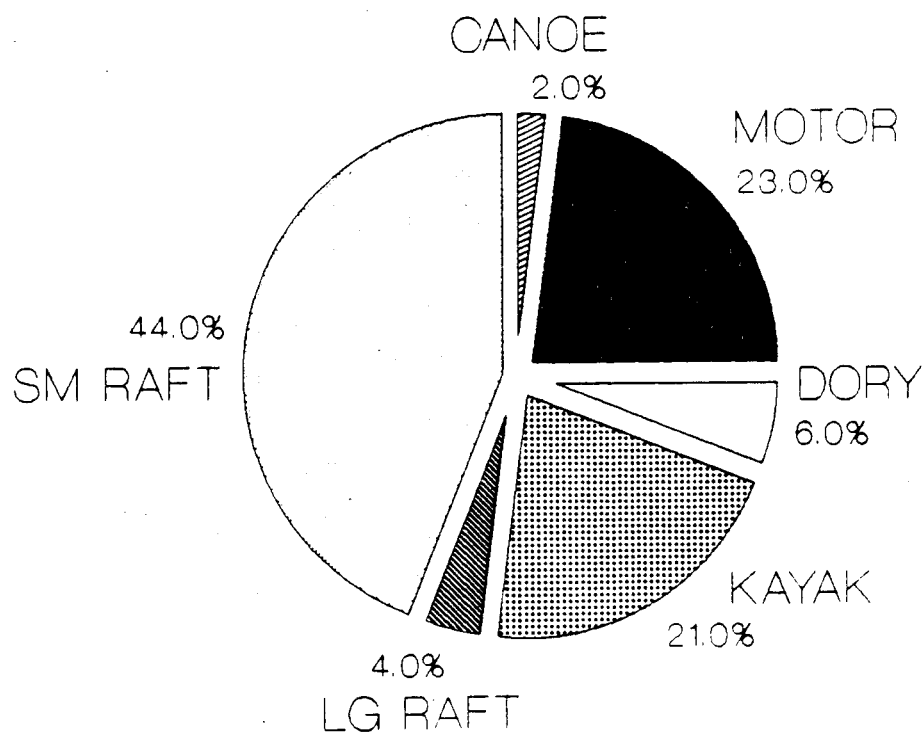
Figure 1 shows the distribution of observations across boat types. Table 4 shows the frequency of observations at the ten rapids for each of the four river flow categories, for each of the six boat types.

The frequency of observations is not uniform among the cells. The target sample size is exceeded for the Medium and High flow categories, and is attained for the Flood category at Crystal rapid with inclusion of the phone survey data, described below. However, the observations at Low flows ($n=100$) provide only sufficient power to detect a change in accident rate of .17 with the same power and confidence level. These calculations, however, are based on a two-tailed test. One could argue that the study needs only detect increases in flip rate from the base rate of .05. This would mean a one-tail design, requiring only 100 observations to detect a change from .05 to .15.

The imbalance in the data set is for several reasons.

1. Seasonal runoff patterns and dam operations made it difficult to obtain a full range of flows. Low flows and Flood flows were especially infrequent during the observation periods.
2. Low flows are most commonly produced by peaking power generation schedules. These operating schedules produce low dam releases during the night and midday. These low flows reach some rapids downstream only during the middle of the night, hence for these rapids no boats are observed at Low flows.
3. Even when a full range of flows reach a rapid during daylight hours, a white-water boater may elect not to run the rapid. The boater may wait for water to rise or fall, or may portage or line the boat through the rapid.

Figure 1
Types of Boats Observed



CANOE: 1 - 2 persons, using single bladed paddles, kneeling. Also covers inflatable, 1 - 2 person crafts.

MOTOR: Motorized craft, usually 22 - 39 feet, powered by 20 - 40 HP outboard motors. Usually pontoon structure, carries 12 - 25 people.

DORY: Rigid wood, fiberglass or aluminum, 14 - 18 foot, flatbottom boat. Powered by one pair of oars.

KAYAK: Single person, closed craft, powered in sitting position with double-bladed paddle.

LG RAFT: (Large Raft) 18 - 22 foot inflatable raft, usually oar powered, carrying 6 - 8 people.

SM RAFT: (Small Raft) 12 - 18 foot inflatable raft, powered by oars or paddles, carrying up to 6 people.

Table 4
Observation Data Set

FLOW CATEGORY					FLOW CATEGORY				
LOCATION:	3-9	10-16	17-31	>31	LOCATION:	3-9	10-16	17-31	>31
HOUSEROCK					GRANITE				
motor	1	11	89		motor			87	
large raft			4		large raft			30	
small raft	8	10	78		small raft			81	
kayak		5	39		kayak			34	
canoe			3		canoe			1	
dory		5	8		dory			13	
TOTAL	9	31	221		TOTAL	0	0	246	0
24 1/2					CRYSTAL				
motor	1	29	72		motor	1	6	259	
large raft	4				large raft	4	6	49	
small raft	25	35	40		small raft	14	119	586	
kayak	5	20	17		kayak	3	83	278	
canoe					canoe	1	16	26	
dory	4		7		dory		14	63	
TOTAL	39	84	136	0	TOTAL	23	244	1261	0
25 MILE					DUEBENDORF				
motor		3	47		motor		8	75	
large raft			1		large raft		4	11	
small raft	2		14		small raft		1	85	
kayak					kayak			32	
canoe					canoe			3	
dory			6		dory		6	7	
TOTAL	2	3	68	0	TOTAL	0	19	213	0
HANCE					UPSET				
motor		1	108		motor		22	62	
large raft		11	19		large raft		4	16	
small raft	4	116	239		small raft		9	61	
kayak		41	122		kayak		1	20	
canoe		3	13		canoe			3	
dory		8	23		dory			19	
TOTAL	4	180	524	0	TOTAL	0	36	181	0
HORN CREEK					LAVA FALLS				
motor			40		motor		34	155	3
large raft			3		large raft		17	20	
small raft			41		small raft	16	238	303	7
kayak			20		kayak	3	137	142	7
canoe			2		canoe	3	21	7	1
dory			7		dory	1	31	37	5
TOTAL	0	0	113	0	TOTAL	23	478	664	23

FLOW CATEGORY TOTALS					TOTALS
BOAT TYPE	3-9	10-16	17-31	>31	
motor	3	114	994	3	1114
large raft	8	42	153	0	203
small raft	69	528	1528	7	2132
kayak	11	287	704	7	1009
canoe	4	40	58	1	103
dory	5	64	190	5	264
TOTALS	100	1075	3627	23	

For these reasons, the data set of observations is unbalanced. The study lacks sufficient observations at Flood flows (>32,000 cfs) and has a marginal number of observations at Low flows. The observations in June, 1986 were scheduled specifically to record flows above 40,000 cfs, but by the time observers were placed in the Canyon, flows had dropped below 33,000 cfs. This gap in the observation data has been addressed by conducting a phone survey of parties that ran the river during the high flow period in May and June, 1986, when flows ranged from 30,000 to 50,000 cfs. The survey focused on problems parties had at Crystal Rapid.

One hundred fifty-nine commercial and 40 private parties ran the river in this period. In spite of many follow-up phone calls, it was extremely difficult to contact commercial guides. Information was obtained about 11 commercial and 36 private trips consisting of 132 boats. This information was combined with the observation data.

Analysis

The uneven distribution of observations over flow ranges and over the rafting season created some difficulties for the data analysis. The overall means for accident rates are disproportionately influenced by the large number of observations at Crystal Rapid and Lava Falls, and by the large number of small rafts observed. Therefore, the overall means are not as interpretable as means for specific types of boats, at specific rapids.

Also, because of the dam operation schedule during the study, river flow levels are unevenly distributed over the observation periods. Likewise, both boat type and trip type (commercial versus private) are unevenly distributed over the boating season. This has created correlations in the data set between river flow levels and several other variables which might affect accident rates, including the type of boat used on a trip, the particular rapid observed, and whether the trip was a commercial or a private trip. Controlling for these intercorrelations was a major requirement for the analysis.

The primary method of analysis was hierarchical analysis of variance (ANOVA). Using this statistical model, the variables that were correlated with river flow levels could be forced into the analysis first. This removed the variance in the dependent (accident) variables associated with these flow-correlates so that, when river flow was entered into the analysis last, the relationship between flow level and

the accident variables was not contaminated by the correlates. This allowed a purer test of the relationship between river flow and each of the accident variables.

For example, imagine that 15% of all boats flip in rapids at High flows, while only 5% flip at Medium flows. If boat types (and other relevant variables) were randomly distributed across flow levels, we could conclude that the difference of 10% was due to the change in flow level. However, if the population of boats at the Medium flow level contained a much larger proportion of motor rigs, the lower flip rate could be due to boat type alone. The hierarchical ANOVA removes the effect of boat type from the raw proportions first, leaving a more accurate measure of the influence of flow level.

Therefore, in the following analyses, the proportions of boats having accidents at different flow levels are the grand mean proportion for the whole population being analyzed, plus or minus the deviation due to the level of the independent variable being assessed, such as flow level. These deviations, as noted, have been corrected for the effect of other covariates such as location, boat type and trip type. These corrected proportions are not equal to the raw (uncorrected) population proportions of boats having accidents, but provide a better index of the relationship between flow level and accidents.

Flow was treated as a categorical rather than continuous variable because (1) the same flow categories have been used by all GCES researchers, (2) the functional relationships between flow and the accident variables are not known a priori but are likely strongly non-linear, thus complicating a regression analysis, and (3) the flow categories are easily treated in an ANOVA design with the many other discrete independent variables.

All statistical analyses were conducted using the SPSS (Statistical Package for the Social Sciences) PC+ software.

Results

Changes in dam release patterns affect the entire river system, not just individual rapids. For this reason, most of the analyses address the effect of flows on accident rates for all rapids taken together, even though individual rapids respond differently to changing flows.

We first report the raw incidence rates for the main accident variables over the entire study period. This provides a context for the analysis of the relationship between river flow level and accident rates which is reported next. The relationship between flow level and accident rate is examined for all rapids combined, for two rapids which typically present problems at high flows, and two which typically present problems at low flows. Next is an assessment of the relationship between river fluctuations (independent of flow level) and accidents and other trip management problems (e.g., stranding boats on beaches). This is based on the observations during steady and fluctuating flow regimes, and the on-river discussions held during those periods.

Following this are analyses of differences among accident rates for various rapids, for type of boat employed, and for type of trip taken (commercial versus private).

Accident Rates Averaged Across Rapids and Boats. To provide a context for the analyses, it is helpful first to consider the general rate of various accidents, averaging across the observed rapids and river flow levels, as shown in table 5 and figure 2. These rates might be considered the average risk one incurs for any serious rapid in the Grand Canyon, averaged across all boat types and flow levels. Note that these accident rates are the average for running a serious rapid, not for an entire trip. It is not possible from this data to calculate a "per trip" accident rate.

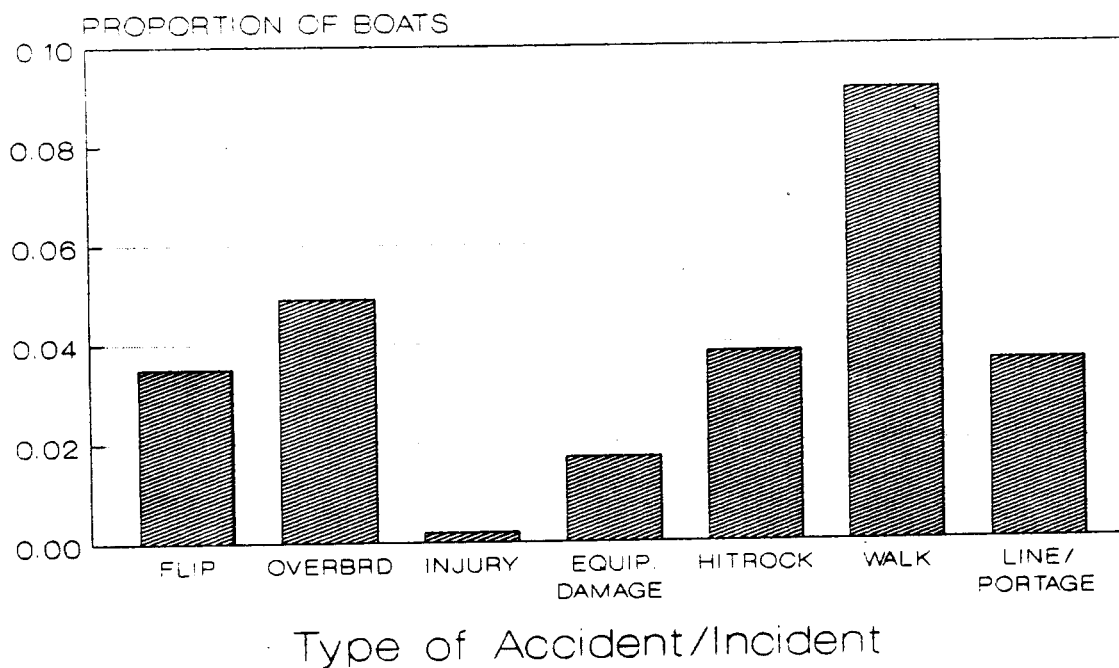
Less than 4% of boats flip in a serious rapid, on average. Approximately 5% lose persons overboard, and less than 2% lose or damage equipment. As expected from the Accident Report Study, the rate of injury is extremely low. From nearly 5,000 boats running rapids, only 8 injuries were observed: 6 slight and 2 incapacitating.

Table 5

Accident Rates "Per Rapid", Averaged Across
Rapids, Flow Levels, Type of Boat, and Type of Trip.

Flipping boat	.034
Person Overboard	.048
Injury	.001
Hit Rock	.038
Equipment damage	.016
Walked	.091
Lined/Portaged	.036

Figure 2
Averaged Accident Rates



Flow level and accidents. To reiterate, the effect of river flows on accidents was assessed by using hierarchical ANOVA to control first for the effect of observation location, type of boat used, and type of trip, before assessing flow. This analysis was done for each accident variable.

Table 6 shows the proportion of boats having accidents, across all observation locations, broken by the four flow categories. In all tables, proportions are rounded to two decimal places. Accident variables significantly related ($p < .05$) to flow, are starred, indicating that the accident rate varies significantly across flow levels (or across the levels of the independent variable being assessed).

Four accident variables are significantly related to river flow level: losing control of an oar, hitting rocks, flipping a boat, and injuries. The chance of losing control of an oar peaks, on average, at Medium flows.

Table 6
Proportion of Boats Having Accident
in Each Flow Category

	Flow Category (1000s cfs)			
	3-9	10-16	17-31	>31
Lost Control of Oar:	.06	.09	.07	.06 **
Boat Struck Rock:	.13	.09	.02	.02 **
Person in Water:	.02	.04	.05	.08
Time in Water ¹ :	1.2	1.5	1.6	1.5
Boat Flipped:	.02	.02	.03	.08 **
Injury:	.00	.00	.00	.02 **
Equipment Lost or Damaged:	.00	.02	.02	.02

** $p < .05$

¹ average rating for boats having person overboard:
 1 = less than 1 minute
 2 = 1 to 5 minutes
 3 = more than 5 minutes

As expected, the chance of hitting rocks is high at Low flows, then decreases at Medium and High flows as rocks become submerged. The increased risk again at Flood flows suggests that boats at these flows may be forced into side-channel rocks by the strong river flows, rather than hitting rocks in the channel.

The risk of flipping is roughly constant at Low, Medium and High flows, but jumps rather dramatically at Flood flows.

The risk of falling or being swept overboard increases consistently as flows increase, but the relationship does not reach the level of statistical reliability. Similarly, the amount of time a person overboard spends in the water is not reliably related to flow level.

Table 6 illustrates the relative risk of boating accidents associated with running rapids at various flow levels. However, it must be remembered that these rates are for those boaters who elected to run the rapid. Boaters may also manage risk by avoiding it -- by electing to not run the rapid (portaging or lining their boats) or run it under more favorable conditions (having the passengers walk around the rapid, in order to lighten the boat). These behaviors reflect the boater's perceived level of risk in running the rapid and serve as secondary indicators of objective risk. The results from Tables 6 and 7 are shown graphically in figure 3.

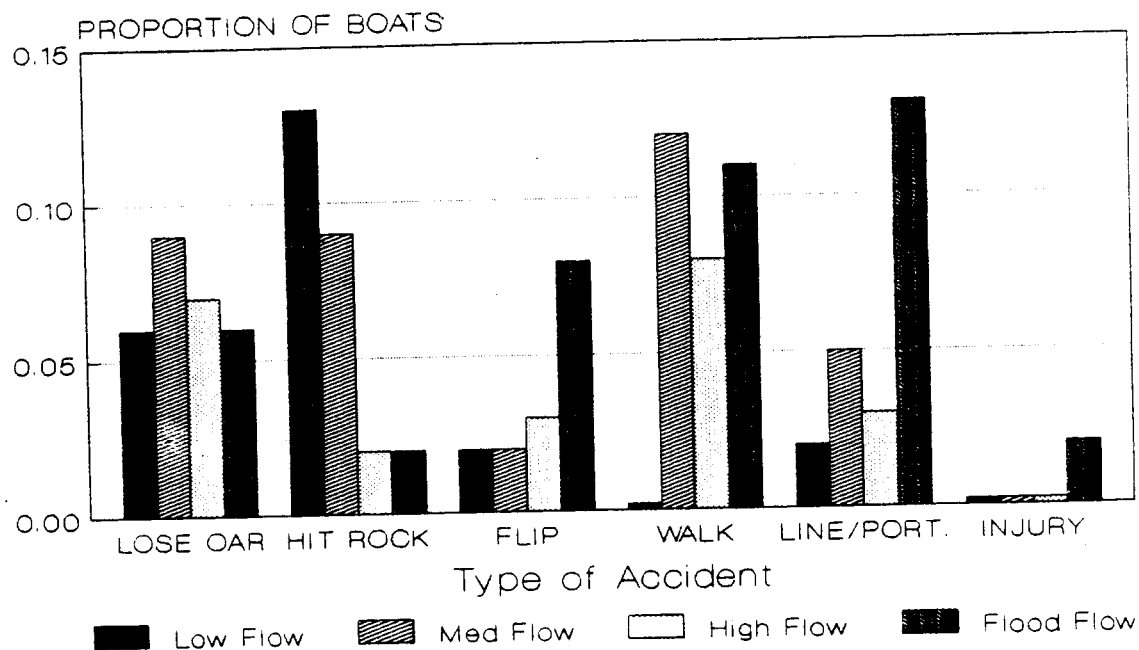
Table 7

Proportion of Boats Being Lined/Portaged
or Having Passengers Walk

	Flow category (1000s cfs)			
	3-9	10-16	17-31	>31
Passengers Walked	.00	.12	.08	.11 **
Boat Lined or Portaged	.02	.05	.03	.13 **

** $p < .05$

Figure 3
Accident Rates - Overall



Both walking around a rapid and portaging or lining boats are significantly related to flow level. While the trend is not perfect, more passengers walk at Medium, High and Flood flows compared to Low flows. The rate of lining and portaging boats also increases as flows increase from Low to Flood flows.

A more complete picture is obtained when one examines both the results above and the analysis presented in table 8 and figure 4 from Crystal Rapid, for which the most Flood flow data is available.

Table 8
Accident Rates at Crystal Rapid

	Flow Category (1000s cfs)				
	3-9	10-16	17-31	>31	
Boat Struck Rock:	.29	.07	.03	.01	**
Person in Water:	.00	.01	.08	.08	**
Boat Flipped:	.01	.02	.05	.08	**
Passengers Walked:	.03	.22	.20	.45	**
Equipment Damage:	.02	.02	.03	.03	
Boat Lined or Portaged:	.02	.07	.06	.18	**
Injury:	.003	.004	.004	.006	**

** $p < .05$

For Crystal Rapid, all accident variables are significantly related to flow level, except equipment damage. The chances of hitting rocks decreases substantially and consistently from Low to Flood flows.

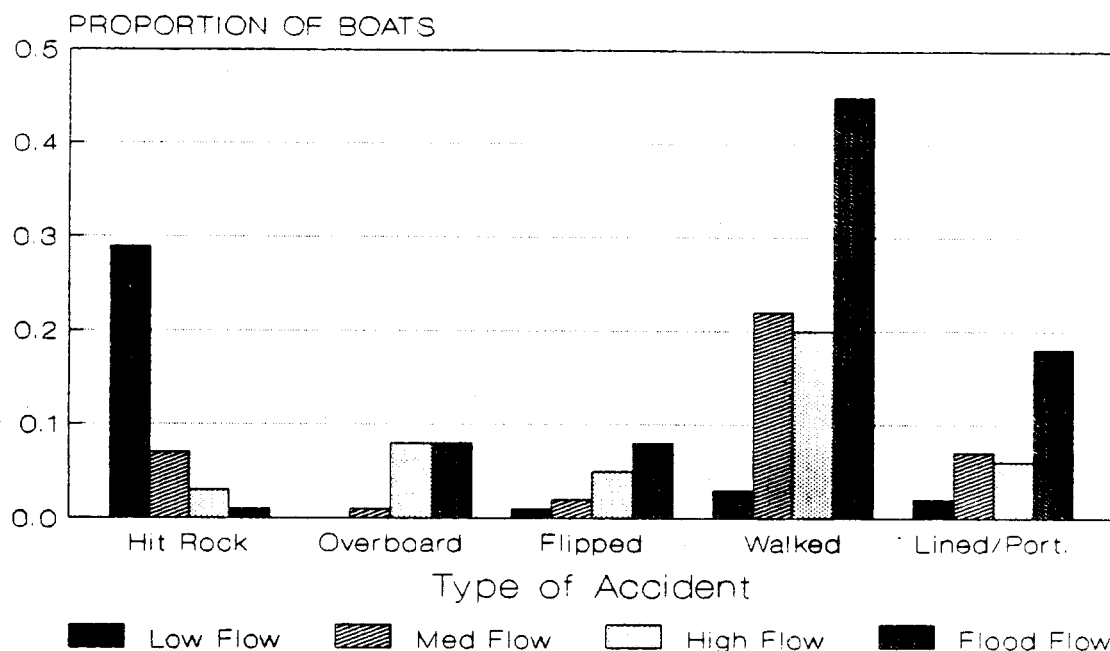
The chances of going overboard and of flipping are quite similar, both increasing from near zero at Low flows to 8% at Flood flows, suggesting that the most common way of falling into the river at Crystal Rapid is by flipping a boat.

The rate of injuries is significantly related to flows. However, the number of injuries is very small: zero injuries at Low and Medium flows, one slight and one incapacitating injury at High flows, and three slight injuries at Flood flows. Thus, while there is a significant trend from Low to Flood flows for injury rate, the small sample warrants caution in interpreting this finding.

One of the most striking results is the relationship between flow levels and either walking around Crystal Rapid, or portaging or lining a boat. Both of these risk management activities start with frequencies near zero at Low flows and increase to substantial proportions at Flood flows. The incidence of walking increases with flows faster than does lin-

ing. This is as expected, since walking passengers around a rapid is easier than lining boats.

Figure 4
Accident Rates - Crystal Rapid



Of the boats lined at Crystal at Flood flows, 61% were small rafts, 35% were kayaks, and 4% were canoes/inflatables. All of the dories, 32% of the kayaks, and 53% of the small rafts had passengers walk.

These results indicate that the observed rate of accidents increases substantially at Crystal Rapid at flows between 31,000 and 50,000 cfs. Further, the boating population exposed to these risks is heavily self-selected -- the boaters running at these flows are not a random sample of all boaters. A large fraction of boaters elect not to run the rapid at these flows, or to reduce risk by having passengers walk.

Because Lava Falls has observations at Flood flows, and because it is a relatively hazardous rapid, it was also selected to be analyzed at each flow level, as shown in table 9.

Losing control of an oar is most frequent at Low flows, perhaps due to the fact that boaters must maneuver around rocks in the rapid at these flows.

Table 9
Accident Rate for Lava Falls

	Flow Category (1000s CFS)			
	3-9	10-16	17-31	>31
Lost Control of Oar:	.29	.20	.07	.07 **
Boat Struck Rock:	.11	.11	.02	.11 **
Person in Water:	.07	.09	.07	.13
Time in Water ¹ :	.94	1.3	1.5	1.4 **
Boat Flipped:	.08	.06	.05	.17
Equipment Lost/Damaged:	.00	.04	.03	.00
Walked:	.00	.08	.03	.10 **
Lined:	.00	.04	.03	.00

** $p < .05$

¹ average rating for boats having person overboard:

- 1 = less than 1 minute
- 2 = 1 to 5 minutes
- 3 = more than 5 minutes

At Lava Falls, unlike Crystal Rapid, the chances of striking rocks is moderately high at Flood flows.

Both the time spent in the water, and the number of persons walking around Lava Falls increase with flows.

In general, the accident variables do not show the strong peaks at Flood flows displayed at Crystal Rapid. This may be due to the small number of observations at Flood flows, as well as to differences in the dynamics of the two rapids. These results indicate problems at High and Flood flows, primarily, for Crystal Rapid and Lava Falls, two rapids known for the challenge they pose at these flows. To focus on difficulties created at low flows, we examined the combined

observations for Hance and Houserock Rapid, two rapids known for their difficulty at low flows.

Only 11 boats were observed at these two rapids below 9,000 cfs. In order to test as best as possible the effect of low flows, we raised the upper cutoff for the Low flow category to 10,999 cfs. This included 38 boats. Since no Flood flow observations are available for these rapids, the analysis includes only the High, Medium, and the new Low flow categories.

Due to the smaller sample size, only a crosstabulation and chi-square were done. Of the accident variables, hitting rocks, and walking around the rapid were significantly related to flows. Twenty-six percent of boats hit rocks at Low flows, 11% at Medium flows and 1% at High flows. At Low flows, 2.6% of boats had passengers walk, 7% at Medium flows, and 1.2% at High flows.

As with the analysis of all rapids combined, this indicates the increased hazard of hitting rocks at lower flows. The other variables are not clearly related to flows, but it must be remembered that this analysis is based on a small number of observations, at flows above 8,000 cfs.

Composite Index of Risk. Since flows affect the rate of various accidents in different ways, it is hard to judge which flow level is safest "overall." This requires aggregating the risk of many kinds of accidents. As an initial effort, we created a composite variable which reflects the risk of all the types of accidents that produce personal injury or equipment damage. In creating this composite, we judged flipping a boat, losing a person overboard, a slight injury, and equipment damage as equally serious. These accidents received a score of 1. Hitting a rock was judged half as serious, with a score of 0.5, because it does not, in itself, involve personal injury or loss. Finally, an incapacitating injury was judged as twice as serious and received a score of 2. The following composite index values were obtained for each flow category, with higher values signifying a higher rate of accidents overall; Low = .14, Medium = .14, High = .11, Flood = .22.

We believe these results are a reasonably accurate index of the relative risk of running the river between 8,000 cfs and 50,000 cfs. While the index for Flood flows provides relatively good coverage of flows above 32,000 cfs, the index for Low flows cannot be applied below 8,000 cfs, due to lack of data. We believe, based on the Accident Records analysis

and the judgment of commercial guides, that accident rates increase significantly below 8,000 cfs. In fact, guides rate flows below 5,000 cfs just as hazardous as flows above 45,000 cfs. Because the guide's judgments of risk have been substantiated empirically at the other flow ranges, we believe their judgments provide an more accurate index for overall risk at Low (below 9,000 cfs) flows than the limited observation data at these flows. Their judgment suggests that the risk index for Low flows would fall closer to the index for Flood flows, perhaps at .18 (table 10). Using this index, High flows are the safest, followed by Medium, Low and then Flood.

Table 10
Overall Risk Index

Flow Category	Risk Index
Low	.18
Medium	.14
High	.11
Flood	.22

Using the same approach, separate indices can be developed for Commercial and Private trips (table 11). As before, the indices for Medium, High and Flood flows are based on the observed accident rates, and the observed rate for Low flows is increased somewhat, to adjust for the absence of data at very low flows.

Table 11
Overall Risk for Commercial and Private Groups

Flow Category	Commercial Risk Index	Private Risk Index
Low	.15	.25
Medium	.11	.18
High	.06	.17
Flood	.10	.33

High flows are safest for both private and commercial trips, with Medium and Low flows presenting increasing hazard for both. The greatest difference between the groups is found at Flood flows, where the risk is much greater for private than commercial trips. This difference in risk level is due primarily to the frequent use of motor rigs by commercial trips but not private groups. These boats handle very high water much easier than the smaller oar boats favored by private parties. The greater hazard for private trips is also reflected in the fact that a much higher proportion of private parties cancel their trips during high water periods, compared to commercial parties.

These indices can be used to compare the overall risk posed by various dam operation schemes. To illustrate the comparison of yearly operating schemes, we have applied the above indices to the actual operations of Glen Canyon Dam for the years 1982, 1984, and 1986, for which the total annual dam releases were 8.2, 20, and 16.6 million acre-feet (MAF), respectively. These years represent typical operations under a wide range of seasonal runoff conditions. Figure 5 shows the monthly hours in each flow range, for the years 1982, 1984, and 1986, as well as the total acre feet passed. Because Flood flows and Low flows have the greatest impact on the risk index, and to simplify the graphs, only Flood and Low flows are shown.

Table 12

White-water Risk Indices for 1982, 1984, & 1986
Actual Dam Operations

Risk Index	
1982	1,304
1984	1,079
1986	1,001
All Low Flow	1,688
All Medium Flow	1,232
All High Flow	797
All Flood Flow	1,409

Figure 5
Hours in LOW and FLOOD Flow

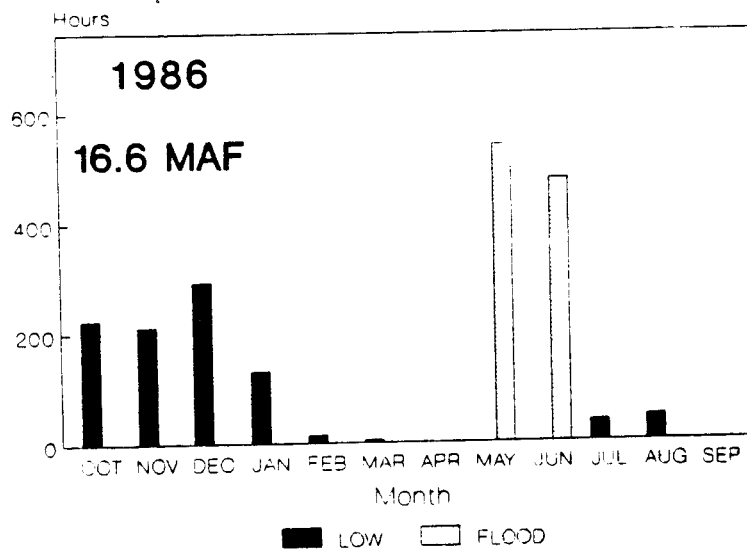
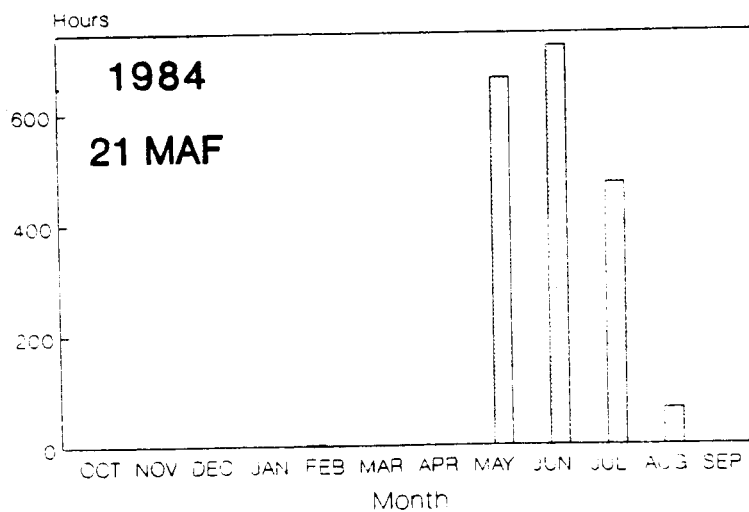
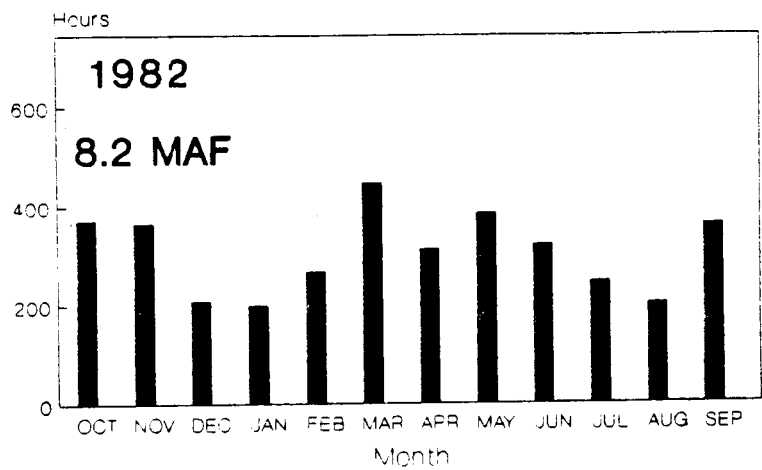
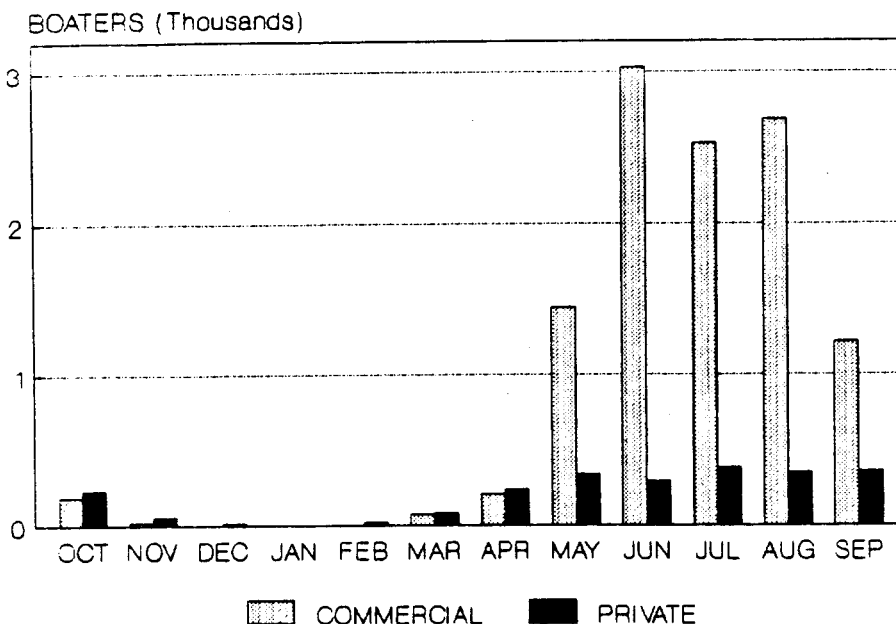


Figure 6

1985 White-water Use Rates

33



The overall index is calculated by multiplying the number of hours in each flow range for each month by the number of commercial passengers in that month (based on 1985 visitation, shown in figure 6), multiplied by the commercial risk index for that flow range. These products are summed over the entire year. The same procedure is used for private passengers, and then the two groups are summed to get the overall risk index for the year.

The overall risk indices for the actual river flows in 1982, 1984, and 1986 are shown in table 12. To provide context for interpreting these yearly indices, table 12 also shows the indices produced by hypothetical years comprised of flows exclusively in one flow range.

The most hazardous year is 1982, followed by 1984 and 1986. Somewhat surprisingly, the risk index is not linearly associated with the total acre-feet passed through the dam. Due to the preponderance of commercial trips each year, the overall index is dominated by the risk indices for that group. Therefore, the overall risk index is most influenced by the amount of Low flows in a year, since these are most hazardous for commercial parties. Looking at figure 5, one can see that 1982 had the most hours of Low flows during the rafting season and therefore has the highest risk index.

The comparison of 1984 and 1986 illustrates the importance of time of year in determining the hazard associated with a given flow level. Nineteen eighty-six receives a somewhat

less hazardous rating, even though it contains some Low flows while 1984 contains none. Very few of those Low flow hours fall in the main rafting season, from May to September, thus they do not impact the overall index significantly. However, 1984 has more Flood flows in the main rafting season, leading to its more hazardous overall rating.

Fluctuations and accidents. While fluctuations in river flows were not identified by white-water guides as one of the more prominent causes of accidents, concerns have been raised that rapidly changing flows could make rapids hard to gauge, particularly by less experienced boaters. This analysis was conducted to see if fluctuations, per se, are associated with higher accident rates. To do this, we compared accident rates during periods when flows were steady to rates during fluctuation periods (flows changing more than 10,000 cfs in 24 hours). To control for the effect of river level we chose observations made only when the river was at High flows, either steady or as part of a fluctuating regime. This level was chosen because sufficient fluctuating and steady flow observations were available only at that flow level.

All steady flow observations from the study that fell in the High flow range (16,000 - 31,000 cfs) were used for the "steady flows group." The "fluctuating flows group" consisted of the observations taken from the fluctuating flow periods, October 1 - December 10, 1985, and August 1 - August 16, 1986, which also fell in the High flow range (16,000 - 31,000 cfs). During these two periods, the largest fluctuations ranged from 5,000 to 27,000 cfs, or a change of 22,000 cfs, while the smallest fluctuations ranged from 10,000 to 20,000 cfs, or a change of 10,000 cfs.

Even though all observations for this analysis were taken from High flows, the flow levels for the steady flow group were somewhat higher than those for the fluctuating group. Therefore, the absolute flow level was entered into the ANOVA first to remove the effect of this small discrepancy. Next were entered boat type, trip type and location to control for any differences between the groups on these variables. Last was entered the dummy variable for fluctuations, which coded whether the observation occurred under fluctuating or steady flows.

The results of the fluctuating flows analysis are shown in table 13. The only accident variable significantly associated with flow regime, steady versus fluctuating, is lining

Table 13

Proportion of Boats Having Accident
Under Fluctuating and Steady Flows

	Fluctuating Flow	Steady Flow
Lost Control of Oar:	.05	.06
Boat Struck Rock:	.02	.02
Person Overboard:	.03	.06
Boat Flipped:	.02	.04
Equipment Lost or Damaged:	.01	.02
Passengers Walked:	.06	.09
Boat Lined or Portaged:	.03	.02 **

** $p < .05$

or portaging boats, which shows a very slightly higher rate for the fluctuation observations.

These results suggest that fluctuating river levels, per se, do not affect the safety of running rapids, when separated from the effect of river level. However, this analysis is based only on High flows. The "fluctuation" observations in this data set are all instances where the river level has just risen rapidly, and is nearing the peak of the fluctuation. It is possible that other results would be obtained at other flows, e.g., for observations at low water in which the river level has just fallen rapidly. This study does not have the necessary data to conduct such an analysis.

Fluctuations and trip management. Concerns have also been expressed about the problems fluctuating flows create for management of river trips. Since certain rapids may not be easily run at low flows, parties may have to wait for the river to rise or drop before proceeding. Falling water may strand boats high on beaches overnight.

To assess these and similar issues, discussions were held with boating parties stopping at observation sites. These discussions were relatively unstructured. Boaters were simply asked if they had experienced any problems on previous reaches of the river, and their responses were tabulated into

general categories.

As in the previous analysis, the boaters were broken into those running under steady flows, and those experiencing fluctuations. Table 14 shows the proportion of boaters making each comment, for the steady flow and the fluctuating flow groups. Due to the relatively small number of discussions ($n = 303$), it was not practical to adjust the response rates for differences between groups in mix of boats and type of trip. Instead a simple crosstabulation and chi-square were done. However, given the magnitude of the significant differences shown in table 14, and the nature of the discussion categories, it seems unlikely that the results would be markedly changed were it possible to remove the influence of boat type and trip type.

The effect of river flow level must be considered, however. It was not possible to equalize these groups based on flow level, as was done in the previous analysis. It is likely that the fluctuation group experienced much lower flows than the steady flow group. Therefore, differences between the groups that might be explained by flow level differences must be interpreted carefully.

Table 14

Percent of Boaters Responding in Each Discussion Category

	Steady Flow	Fluctuating Flow	
Rapid judged dangerous at current flows:	0	8	**
Waited for water to drop to run rapid:	0	.9	
Waited for water to rise to run rapid:	1.1	3.8	
Low water slowed trip:	0	9.4	**
Plans changed due to beach loss/reduction:	2.2	3.8	
Boat hung on rocks due to low water:	0	5.2	**
Boats stranded on beach due to falling water:	2.2	13.1	**
Moved boats during night:	0	12.2	**
Concerned about flow impacts on environment:	0	3.8	**
Unhappy about green slime/ walking on rocks:	0	1.9	
Unhappy with fluctuations:	1.1	14.1	**
Unhappy with low water:	0	8.0	**

** p < .05

An example of this is item 1, "Rapid judged dangerous at current flows." Eight percent of those in the fluctuation group made this comment, while 0% responded this way from the steady flow group. It is possible that this result is due to the fact that the fluctuation group experienced low flows, while the steady flow group did not, rather than being due to the effect of fluctuating flows, per se. In this regard it is notable that 8% of the fluctuation group also complained about low water in general, 9% said that low water slowed their trip, and 5% had boats hung on rocks due to low water, while none of the steady flow group raised these concerns.

The remainder of the significant differences, however, seem best explained as a true result of fluctuations. Not surprisingly, significantly more boaters running under fluctuating flows had boats stranded on beaches when water levels fell, and had to move boats at night to avoid this beaching. The fluctuation group also had significantly more concerns about the effect of flow levels on the environment. For example, during fluctuations, boaters reported observing high rates of beach erosion as the river levels rose and fell.

Accident rates for individual rapids. Rapids differ in the risk they pose for accidents. Table 15 shows the effect of location on accident rate, after controlling for differences in boat and trip population and flow levels. In order to maintain adequate sample size, this analysis is averaged across all flow levels.

The rapids observed differed significantly on all accident variables. The greatest hazard for striking rocks is found at Hance and Crystal Rapids, while losing an oar is most likely at Lava Falls, followed by Granite and Crystal.

Going overboard is most frequent at Crystal Rapid and Lava Falls, while the greatest average time spent in the water is at Granite Rapid. Both flips and loss or damage to equipment are most common, once again, at Crystal Rapid and Lava Falls. Crystal Rapid also has, by a large margin, the highest proportion of passengers walking. It also is first in lining or portaging boats, followed closely by Deubendorf.

Table 15
Accident Rates for Different Rapids³

	H O U S E R O C K	2 4 1 / 2	2 5 M I L E	H A N C E	H O R N	G R A N I T E	C R A S T A L	D U E B E N D O R F	U P S E T	L A V A F A L L S
Struck Rock:	.01	.00	.02	.06	.03	.04	.05	.02	.03	.04
Lose Control Oar:	.01	.00	.02	.04	.01	.09	.09	.01	.00	.12
Person in Water:	.02	.02	.03	.02	.02	.05	.06	.02	.03	.08
Time in Water ¹ :	1.4	- ²	- ²	1.1	1.9	2.8	1.8	.9	1.0	1.4
Boat Flipped:	.01	.01	.02	.01	.01	.03	.04	.01	.02	.05
Equipment Lost:	.01	.01	.01	.00	.00	.02	.03	.00	.01	.03
Passenger walked:	.02	.03	.02	.03	.01	.03	.19	.01	.01	.04
Lined or Portaged:	.01	.02	.03	.01	.03	.03	.05	.04	.02	.02

¹ - average rating for boats having person overboard,
 1 = less than 1 minute
 2 = 1 to 5 minutes
 3 = more than 5 minutes

² - insufficient occurrences or observations

³ - all factors significantly related to location

Boat type and accidents. The type of boat used is also related to the likelihood of accidents. Table 16 shows the association between boat type and accident rates, controlling for the type of trip, location, and flow levels.

Table 16
Accident Rates by Type of Boat

	Motor	Boat type		Kayak	Canoe	Dory	
		Lg Raft	Sm Raft				
Lost Control of Oar:	.00	.09	.12	.00	.02	.16	**
Boat Struck Rock:	.04	.11	.06	.00	.11	.03	**
Person in Water:	.02	.02	.05	.07	.22	.07	**
Time in Water ¹ :	.15	.83	1.65	1.65	1.67	1.25	**
Boat Flipped:	.00	.00	.02	.06	.18	.04	**
Equipment Lost/Dmg:	.01	.02	.03	.02	.01	.02	**

** p < .05

1 - average rating for boats having person overboard,
 1 = less than 1 minute
 2 = 1 to 5 minutes
 3 = more than 5 minutes

Dories and small rafts are most likely to lose control of oars, while motor rigs and kayaks do not have this problem.

Hitting rocks is most common in large rafts (perhaps due to limited maneuverability), and canoes.

Persons are most likely to go overboard from canoes, followed distantly by kayaks and dories. Once overboard, persons from canoes have the longest time in the water, followed closely by small rafts and kayaks. Persons falling off motor rigs spend a very short time in the water, on average.

Canoes are most likely of all boats to flip in rapids, with kayaks a distant second.

Small rafts are observed to have the most frequent loss or damage to equipment, with dories, kayaks, and large rafts close behind. Most cases of lost equipment involved oars being lost overboard.

Trip type and accidents. The differences in accident rates between commercial and private trips are quite small, but consistent, as shown in table 17.

Table 17

Accident Rates for Commercial Versus Private Trips

	Trip Type	
	Commercial	Private
Lost Control of Oar:	.06	.08 **
Boat Struck Rock:	.03	.06 **
Person in Water:	.04	.06 **
Time in Water ¹ :	1.52	1.57
Boat Flipped:	.02	.04 **
Injury:	.002	.002
Equipment Lost or Damaged:	.01	.01

** $p < .05$

- ¹ - average rating for boats having person overboard,
 1 = less than 1 minute
 2 = 1 to 5 minutes
 3 = more than 5 minutes

A more narrow but more controlled comparison of commercial versus private trips can be constructed by comparing just commercial versus private trips in small oar rafts at Crystal Rapid, controlling for any differences in flow level between the groups, as shown in table 18.

Table 18

Accident Rates for Commercial versus Private Trips
in Small Oar Rafts at Crystal Rapid

	Trip Type	
	Commercial	Private
Boat Struck Rock:	.04	.08 **
Person in Water:	.06	.10 **
Boat Flipped:	.03	.07 **
Injury:	.004	.004
Equipment Lost or Damaged:	.04	.02

** $p < .05$

Chapter III

CONCLUSIONS

As part of the GCES, Recreation Component, several studies were conducted to determine whether the Colorado River flow levels produced through Glen Canyon Dam operations are related to the incidence of white-water boating accidents in the Grand Canyon. This goal was achieved by (1) surveying experienced white-water guides and private boaters to assess the relationship they perceive between river flow levels and accident rates, (2) analyzing records of boating accidents to correlate reported accidents with river flows, and, (3) observing boats running rapids under a range of flow levels. These three avenues of inquiry converged on the conclusion that river flow levels are related to white-water boating accident rates in a statistically reliable fashion.

The conclusions of the studies are summarized beginning with experienced boater's perceptions regarding the effect of flows on accidents, continuing with the analysis of accident records, and concluding with the observation study.

Guides and Private Boater's Beliefs

Guides and private boaters believe that river flow levels affect accident rates. Flood flows and Low flows are believed to be the most hazardous conditions, such that guides do not believe passengers can be carried safely below approximately 8,000 - 9,000 cfs or above 45,000 - 60,000 cfs, depending upon the type of boat employed.

Fluctuating flows are not considered as significant a factor in river safety. The empirical analyses results, described below, agreed closely with these perceptions.

Accident Records

The analysis of accident records show no significant overall relationship between flow levels and the reporting of serious accidents. However, for several reasons, this is a relatively weak test of the relationship between flow levels and accident rates. The accident records analysis did find a significant relationship between flows and accident rates at Crystal Rapid, with higher flows associated with substan-

tially higher rates. These flood-flow accidents at Crystal Rapid occurred in 1983, at flows above 50,000 cfs. They involved three motor rigs flipping, two other boats being destroyed, and over 100 persons evacuated.

Observed Accidents

The observation study found significant associations, across ten major rapids, between river flows and the rate of four accident variables; losing control of an oar, hitting rocks, flipping and injuries. The frequency of hitting rocks decreased with flows, while the other accidents increased with flows. At Crystal Rapid, flow level was significantly related to six accident variables; hitting rocks, falling overboard, flipping, injury, walking around the rapid, and lining or portaging boats. All rates increased with flow level, except for hitting rocks, which decreased.

At Crystal Rapid, a large fraction of boaters choose to avoid running at Flood flows, with nearly 20% lining or portaging boats and 45% of boats having passengers walk around the rapid.

Similar trends in accident rates and avoiding accidents are found at Lava Falls, although not as pronounced.

The river guides have indicated their belief that very low flows also are associated with increased accidents. Experienced guides plan their trips to avoid certain rapids (e.g., Horn Creek) at very low flows. While not statistically significant, the Accident Record Study found a trend toward increased accidents at Low flows at Horn Creek.

The Observation Study had limited data at Low flows, with no observations below 8,000 cfs. An analysis of the available data for Hance and Houserock Rapids (two rapids identified by guides as problematic at low flows), showed a consistent increase in striking rocks at Low flows but no reliable trends in the other accident variables at Low flows.

In summary, the current observation data on accidents at very low flows is quite limited, but show increased risk of hitting rocks, and trends towards increased accidents overall.

We propose the following index of the risk of running rapids at different flows, based on the empirical data and the judgment of experienced guides. This indicates that, overall, the greatest risk occurs at Flood flows, followed by Low and Medium flows, with High flows least hazardous.

Flow Category	Risk Index
Low (>9,000 cfs)	.18
Medium (9,000 - 15,999 cfs)	.14
High (16,000 - 31,500)	.11
Flood (>31,500 cfs)	.22

White-water guides also identified fluctuations in river flows as related to accident rates, although the significance attached to this factor was much less than other factors such as boater experience and extremely high and low river flows. This issue was addressed by comparing accident rates at the same flow levels during periods of constant versus fluctuating flows. No differences were found in the accident variables between constant and fluctuating flows except for a very slightly higher rate of walking passengers around rapids during fluctuating flows.

The risk of accidents is significantly affected by the type of boat employed. For example, considering the combined rate of flipping or having persons fall overboard, there is a substantial spread between boat types. Motor rigs and large rafts have the lowest rates, approximately .01. Small rafts, dories and kayaks comprise the middle group with rates of .035, .055, and .065 respectively, with the highest rates occurring for canoes/inflatables at .20.

In fact, the relationship between boat type and accident rate is stronger in most cases than the association between flow level and accidents. For example, at Lava Falls the rate of flipping varies by .12 across flow levels, but varies by .21 across boat types. Only when looking at hitting rocks at Crystal Rapid and losing control of an oar at Lava Falls does one see a stronger effect of flows than of boat type.

Whether one took a commercial or private trip had a small but consistent effect on likelihood of an accident, even when controlling for the different type of boats used. Private parties were somewhat more likely to lose control of an oar, strike rocks, have someone fall overboard, and flip boats than were commercial parties. The difference in accident rate between the two types of trips averaged .02. This difference may be due to the greater amount of experience commercial guides have, on average, compared to private trip leaders, or to a greater conservatism on the part of commercial guides, who must always consider first the safety of their paying passengers.

Needed Additional Research

The most important supplement to this study would be the addition of constant Low flow observations below 8,000 cfs (approximately 150 boats) and additional Flood flow observations (approximately 100 boats). This would provide a much more reliable empirical estimate of accident rates at Low and Flood flows. Also useful would be 150 observations at the low end of a fluctuating regime, e.g., below 10,000 cfs. This would determine whether the present results regarding the effects of fluctuations on accidents held at Low flows.

Chapter IV

DISCUSSION

Representativeness of the Data

When considering these results as a basis for management decisions, an important question is whether the data evaluated is representative of future conditions to which management efforts will be applied. Are either the population of boaters or the river flows studied unusual in some way that would prevent the application of these results to future time periods?

We have no reason to believe that the boating population studied is significantly atypical. The analysis of accident records covered a three year period (1981 - 1983), and the observation study sampled six months covering Spring, Summer, and Fall in 1985 and 1986. Of course, the surveys of white-water guides and private trip leaders covered their experiences from many years.

If this group is any way unusual, it might be in their relatively great amount of experience with very high flows. Due to the high runoff in 1983 - 1986, there has recently been an unusual amount of relatively high, steady flows, and fewer periods of low or fluctuating flows. Thus the current group of guides and private trip leaders might be said to be quite experienced with high flows, and less familiar with low and fluctuating flows.

Any time that flow regimes are changed dramatically (e.g., changes from long periods of fluctuating flows to high steady flows), all river runners become, to a certain extent, novices. It is reasonable to expect that accident rates, or adaptive measures such as walking passengers and lining boats, might increase following a substantial change in flow regime, until boaters gain familiarity and experience with the new flow pattern.

Practical Significance of the Results

The relationships between accidents and flows reported here, in addition to being statistically reliable, are supported by multiple types of data (expert judgment, official records, direct observations) and show a consistent pattern. Thus we

are confident that the relationships are real. Further, while a correlation between flows and accidents cannot prove a causal relationship, we can find no plausible explanation for the observed association other than that differences in flow levels cause differences in accident rates.

Interpreting the practical significance of the results is less straightforward. Does flow level affect boating hazards enough to warrant control of flows in the interest of safety? If so, how much should flows be controlled? How much risk is acceptable, even desirable by boaters?

These are questions that must be answered jointly by managers and white-water boaters. While boaters participate voluntarily in white-water boating, there are some conditions that they find "too risky." These concerns were expressed during the public meetings for the Peaking Power studies, and have also been expressed in the surveys reported here.

Managers may also find certain conditions "too risky," for two reasons. First, the conditions may be so extreme that to allow persons to run the river under those conditions could possibly be considered negligent management. Further, the accident rate may, under such conditions, be so high as to create an unacceptably high demand on rescue services. Both of these "limits" appear to have been exceeded during the very high river flows (over 70,000 cfs) in June, 1983, when officials suspended launches at Lees Ferry for two days and required, for a period of 30 days, that passengers walk around Crystal. This order was given following the evacuation of more than 100 boaters whose boats had been damaged or lost in accidents.

These concerns must be balanced against recognition that risk and challenge are an integral part of the Grand Canyon white-water experience. In surveys of river runners, the majority stated that rapids were one of the most important reasons for coming to the Grand Canyon (GCES Report C-2). Running a boat through Crystal Rapid or Lava Falls is often the most dreaded and most treasured part of a Grand Canyon boat trip, as illustrated by the following accounts.

" 'I hate this rapid!' Already, from all possible angles we had spent half an hour studying this all-too-familiar menace to navigation. It was indifferent to our scrutiny. The Colorado, raging at 40,000 cfs past Crystal Creek at mile 98 presented no reasonable route for an oar boat. But it did offer a window of survival - if you rowed your heart out and your timing was perfect...

Five minutes later we pulled into the first available beach for lunch and, to kill post-adrenalin-shakes, an A.B.C. party - Alive Below Crystal. That night we camped below Bass Rapid and celebrated again..." (Ghigliaeri, 1986).

"River running has a constant companion whose absence would deflate the sport like a nail through the tread of a tire. The companion is danger, and its presence marks the difference between a Disneyland ride and a run through Cataract Canyon. Without danger, without the risk, however remote, of being hurt or being killed, running rivers would be only fun. Add danger, and running a river becomes, among other things, an elemental microcosm of survival, a return to something primitive where instinct matters more than intellect, where senses are sharpened, awareness is heightened and where being alive becomes somehow more immediate, urgent and real" (Bolling, 1986).

Evaluation of the significance of the relationships reported here must therefore include input from the white-water boaters themselves. Existing boater input indicates an aversion to running the river below 8,000 or above 45,000 cfs. The current empirical results concur in the view that risks increase rapidly above 32,000, and that the risk of hitting rocks increases substantially below 10,000. Boaters should be asked to evaluate these results and indicate their preferred "safety limits."

Similarly, managers must consider their responsibilities for risk management. Currently, white-water boaters in Grand Canyon are required to meet Coast Guard white-water safety standards for equipment. The actions of managers in 1983 to mitigate the risks posed by very high flows suggest recognition of Federal responsibility for risk management but do not define the limits or the basis for such responsibility. Consideration of these questions, jointly with the affected recreation groups, could create a more comprehensive policy framework within which to select and apply risk management options. We believe that the findings and observations presented in this report will assist recreationists and managers in analyzing their alternatives and making decisions.

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